

Space Test Program

USNO-901 Full-Sky Astrometric Mapping Explorer (FAME)

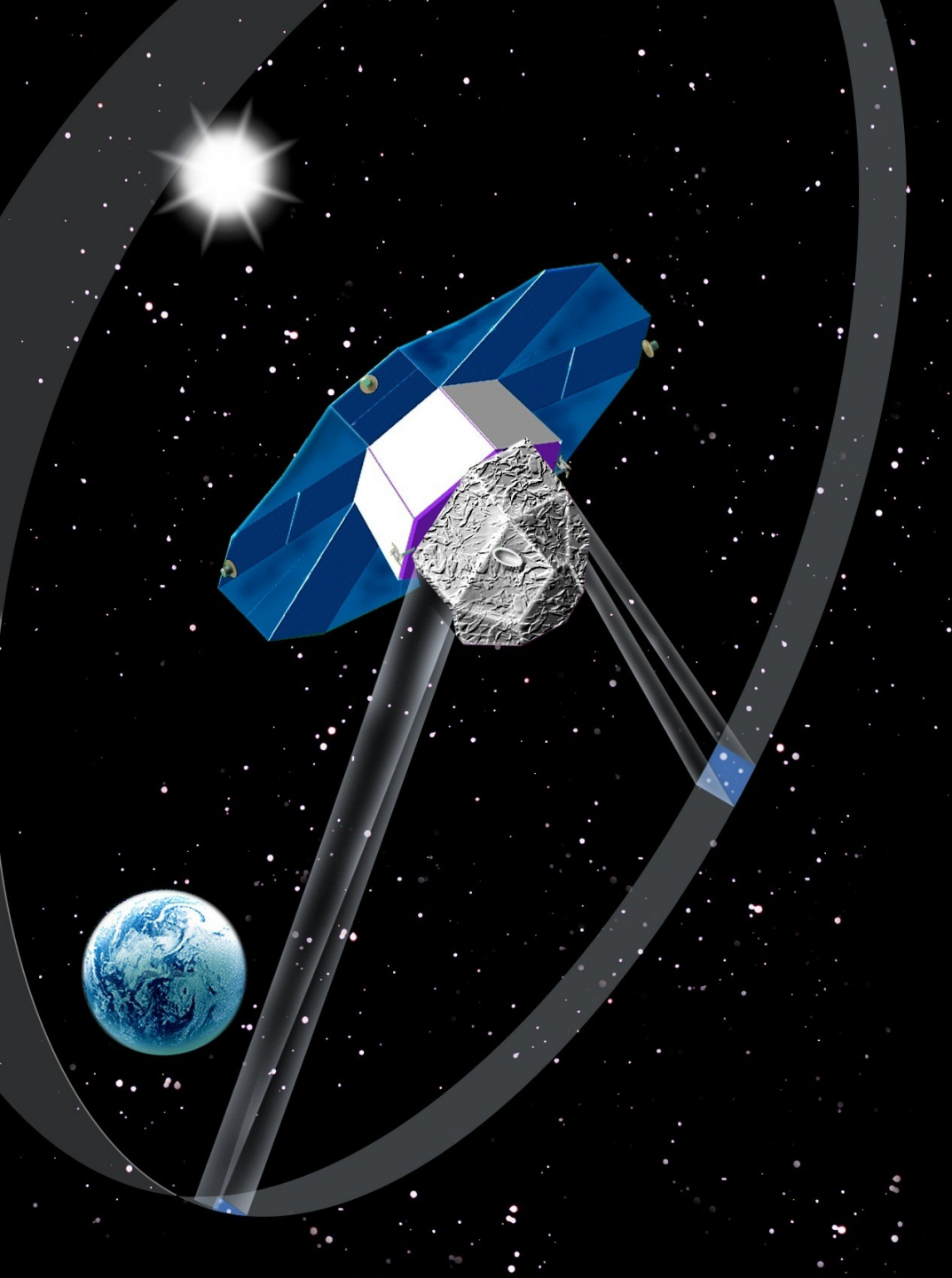
Presentation to

DoD Space Experiments Review Board

15 April 1999

Dr. Scott D. Horner, USNO





Full-sky Astromet ric Mapping Explorer

<http://www.usno.navy.mil/fame>

USNO-901 Full-Sky Astrometric Mapping Explorer (FAME)

CONCEPT

- **A joint program involving the U.S. Naval Observatory, the Naval Research Laboratory, Lockheed**

Martin, Smithsonian Astrophysical Observatory, IPAC, and Omitron Incorporated.

- **Developed from the Navy Astrometric Satellite concept (NRL-307)**
- **FAME is a small satellite that will use dilute aperture technology to perform an all-sky astrometric survey of unprecedented accuracy.**
 - **Full catalog of 40 million stars within 2.5 kpc; photometric data in four color bands**
 - **Positions of bright stars ($5 < m_v < 9$) to $< 50 \mu\text{as}$**
 - **Positions of fainter stars ($9 < m_v < 16$) to $< 300 \mu\text{as}$**
 - **2.5 year mission provides accurate measurements of stellar parallaxes and proper motions, and identifications of hitherto unresolved multiples**
- **Improving star position accuracies by a factor of $\sim 1,000$ will enable major improvements in geolocation, geopositioning, and autonomous navigation.**

USNO-901 Full-Sky Astrometric Mapping Explorer (FAME)

JUSTIFICATIO
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High Accuracy Astrometry

DoD Relevance (1 of 2)

♦ **Precise inertial reference frame**

➔ **Astrometry and reference frame maintenance are Navy (USNO) mission**

▢ **Astrometric requirements currently met by Hipparcos astrometric satellite data 1991.25**

- **Degrades with time due to proper motion inaccuracies**
- **In 2010 current requirements no longer met**

▢ **FAME provides 0.000050 arcsecond precision for short term needs**

▢ **FAME provides 0.00010 arcsecond precision over the long term to meet current and future needs**



High Accuracy Astrometry

DoD Relevance (2 of 2)

- ♦ **Develop next generation Star Trackers for space**
 - ➔ **FAME serves as pathfinder for Star Trackers in space**
 - Characterize materials and techniques
 - Precursor for NASA - future NASA astrometry missions (SIM, TPF)
 - Precursor for space based imaging missions
 - ▢ **Develop technology for inertial orientation and navigation using only stellar data**
 - Precursor for future high precision star trackers
 - Navigation by stars only, 1.0m precision in space
- ▢ **Fundamental astronomy and astrophysics**
 - ▢ **Stellar distances, parallaxes, proper motions**
 - ▢ **Planetary information**
 - ▢ **Galactic structure, rotation, cosmic distance scale**

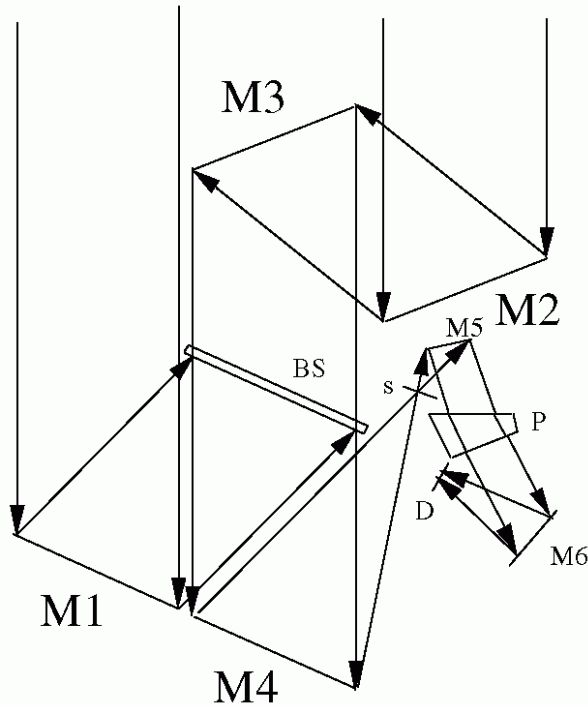


Reference Frames

- ✦ **Fundamental frame based on extragalactic radio sources** ~0.2 mas accuracy
- ▮ **Optical reference frame**
 - ➔ **Based on Hipparcos** ~1 mas in 1991
 - ▮ **Tied to radio frame** ~0.6 mas in 1991
 - ▮ **Degrades with time**
 - ▮ **Accuracy depends on magnitude**
 - ▮ **Possible rotation with respect to fundamental**
- ▮ **Dynamical reference frame**
 - ▮ **Based on solar system**
 - ▮ **Ephemerides dependent**
 - ▮ **Inner & outer solar systems different**
- ▮ **Terrestrial reference system**
 - ▮ **Based on Geoid**
- ▮ **Determination of all frames and links from U.S. Naval Observatory**

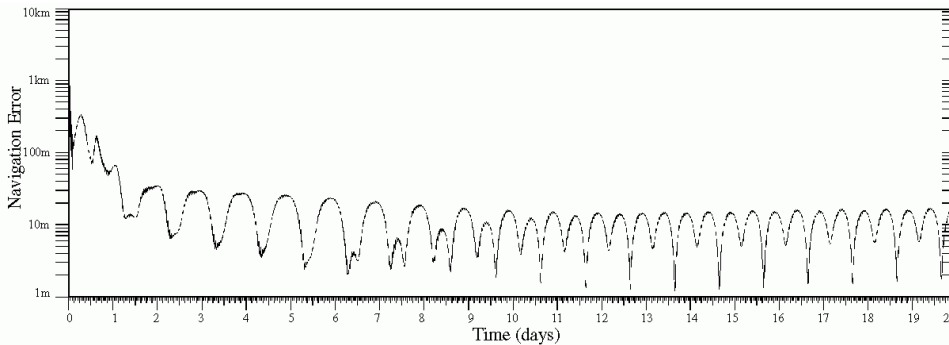


Space Navigation Concept

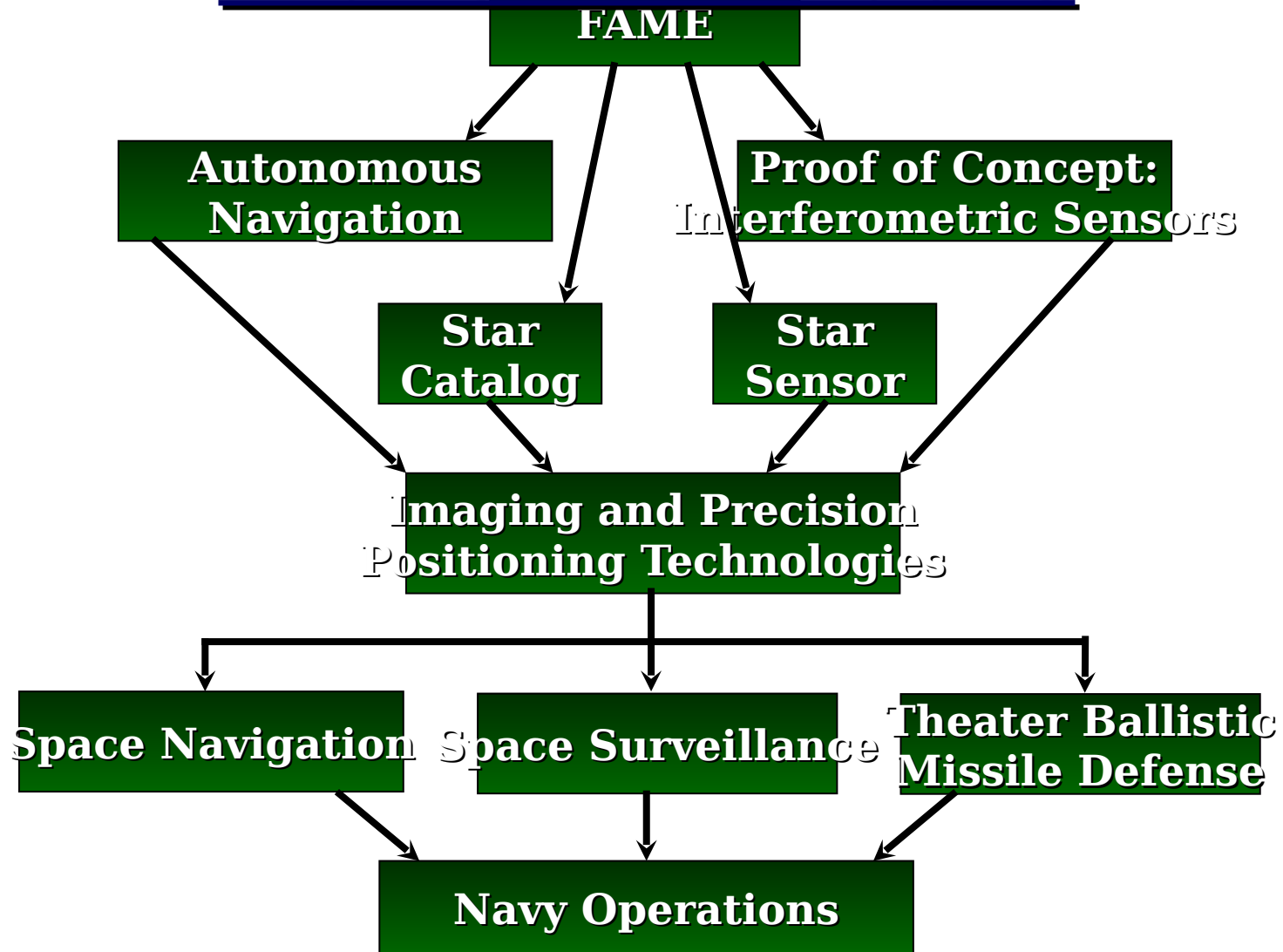


- ▢ Precise stellar positions enable space navigation at meter accuracy
- ▢ Similar to inertial navigation unit (INU) but based on stellar inertial reference frame
- ▢ Stellar aberration determine position
- ▢ Proposed design
 - ➔ < 40 kg
 - ▢ < 130 W
 - ▢ Monolithic ULE Glass construction
 - ▢ 1028x1028 CCD Array

◆ Simulation demonstrates 10 meter resolution assuming 10 sec updates and 20 μ s accurate star map.



FAME Technology/Data Transition Paths



USNO-901 Full-Sky Astrometric Mapping Explorer (FAME)

DETAILED OVERVIEW

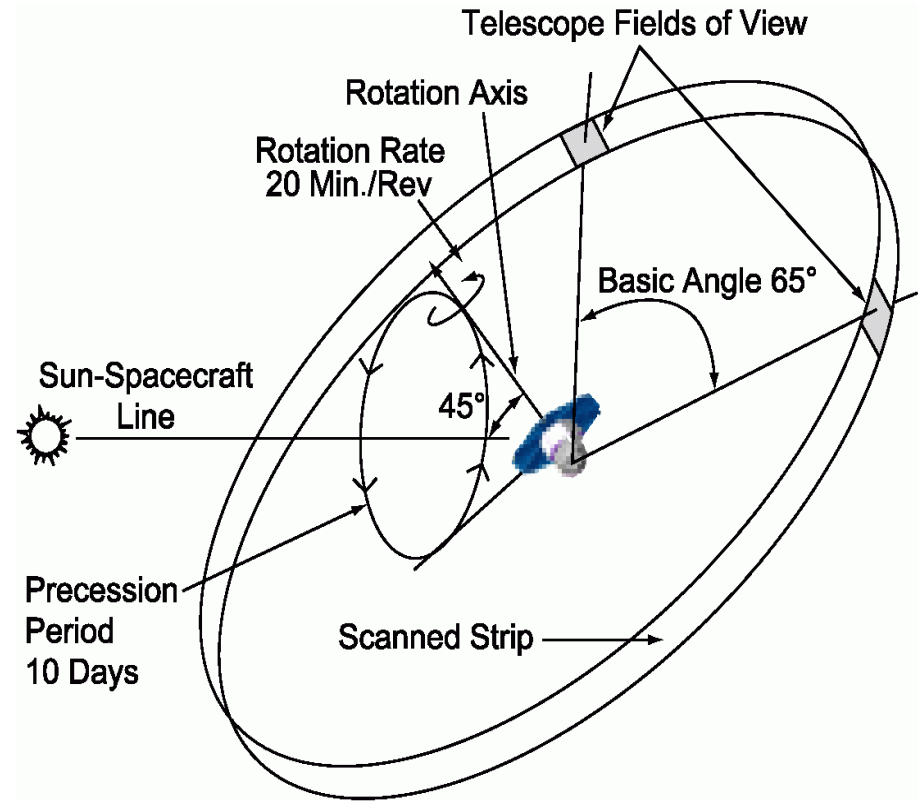


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FAME Mission Description

- ♦ The telescope has two fields-of-view separated by a 65° basic angle
- The spacecraft will rotate with a 20 minute period with the apertures sweeping out a great circle on the sky
- The spacecraft rotation axis is at a 45° angle to the Sun
- The solar radiation pressure on the solar shield results in precession about the Sun-spacecraft line with a 10 day period

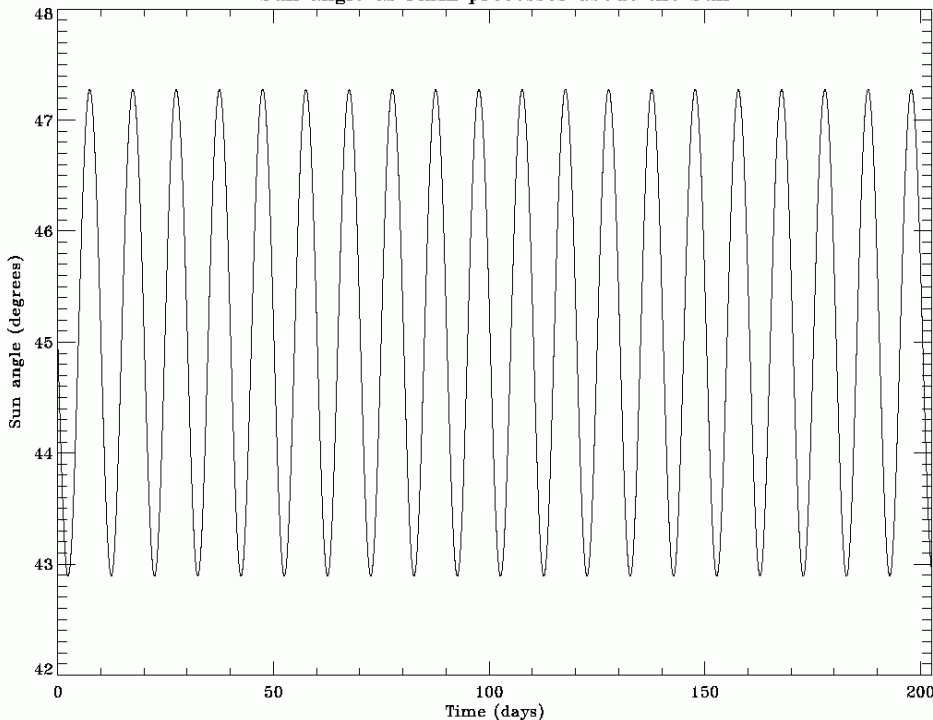


The FAME observing concept - The axis of the FAME spacecraft is pointed 45° from the Sun and precesses around the Sun with a 10 day period. The FAME spacecraft rotates with a 20 minute period. The two fields of view are normal to the rotation axis and are separated by a 65° degree basic angle.



Solar Radiation Precession

Sun angle as FAME precesses about the Sun

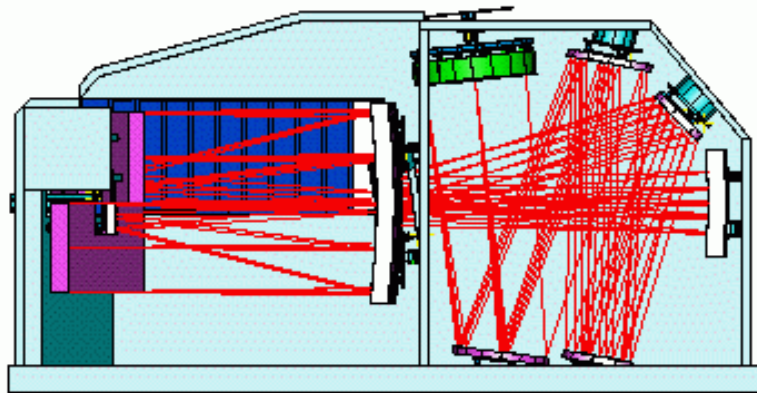
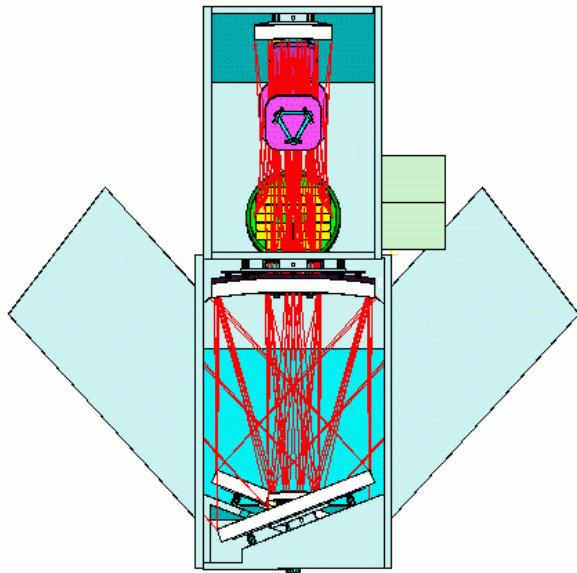


Model of FAME precession - This shows the results of a model of the FAME precession from solar radiation pressure on the Sun shield. The Sun angle varies from the nominal 45° by a few degrees but does not have a linear drift towards or away from the Sun.

- ♦ Deployed Sun shield is slightly swept back and acts as a solar sail
- Solar radiation pressure on the Sun shield produces a torque that move the spin axis
- Sweep of shield is adjusted at deployment to tune the precession rate
- This results in smooth precession (thruster firings are rare) resulting in long periods of coherent rotation



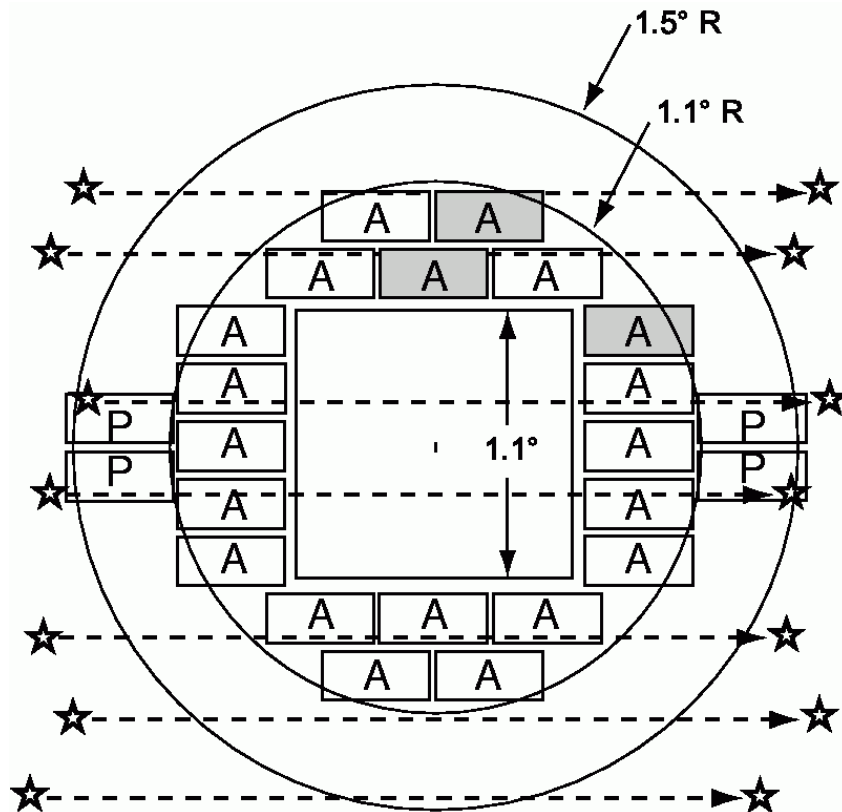
FAME Instrument Description



- ◆ Instrument developed by Lockheed Martin
- ▮ Total weight 165 kg
- ▮ Total power 250 W
- ▮ Instrument optics
 - ➔ Two input apertures
 - ▮ 50 × 25 cm aperture size (each)
 - ▮ 400 to 900 nm spectral range
- ▮ Back illuminated CCDs



FAME Instrument Description



The FAME focal plane - 24 2k · 4k CCDs arranged around a 1.1° radius from the center of the field of view. Devices marked with 'P' are the 4 photometric CCDs and devices marked with 'A' are the 20 astrometric CCDs. The 3 'gray' devices have neutral density filters for astrometry of brighter stars.



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♦ **Telescope produces images of Stars using 24 large format CCDs**

➔ **Images of stars are continually traversing CCD array as the spacecraft rotates**

▢ **CCDs use time delay integration**

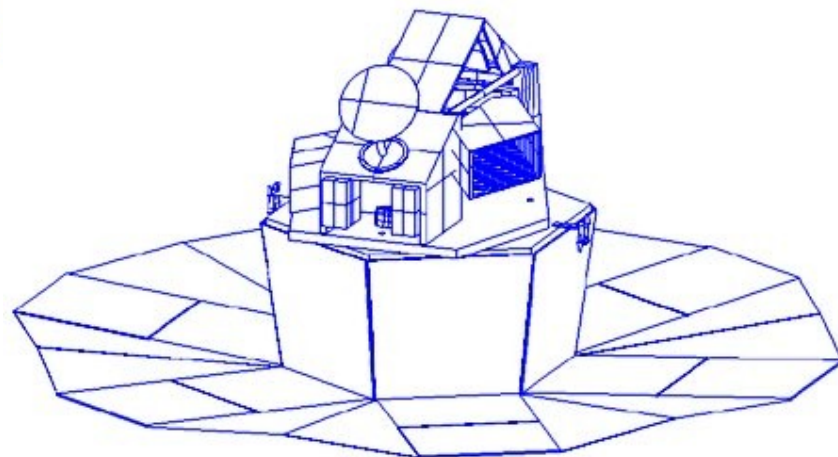
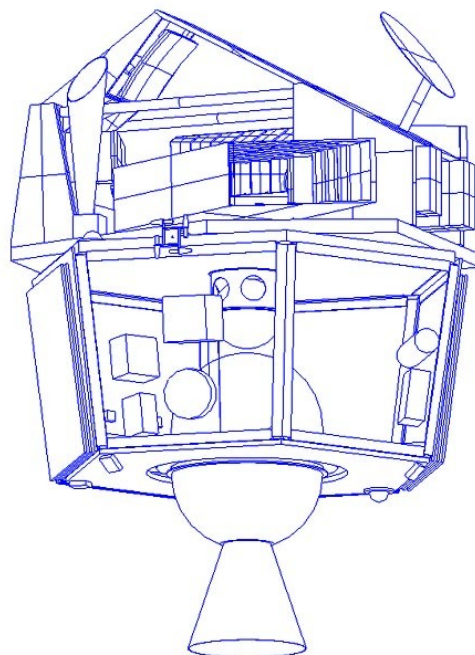
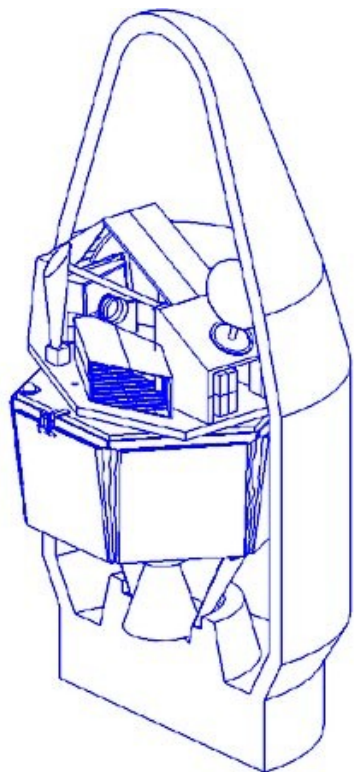
▢ **Synchronization of CCD clock rate and image motion is assured via rotation rate sensors**

▢ **Star images are time tagged, windowed, and transmitted to Earth.**

▢ **3 CCDs are covered by neutral density filters for astrometry of bright stars**

FAME Spacecraft Bus

Description



**Instrument cover
removed for clarity in
all views**

**Spacecraft in
Delta II 2.9m
fairing**

**Spacecraft before
solar shield
deployment**

**On orbit
configuration**

**✦ Spacecraft design uses component heritage
from Clementine**



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LOCKHEED MARTIN

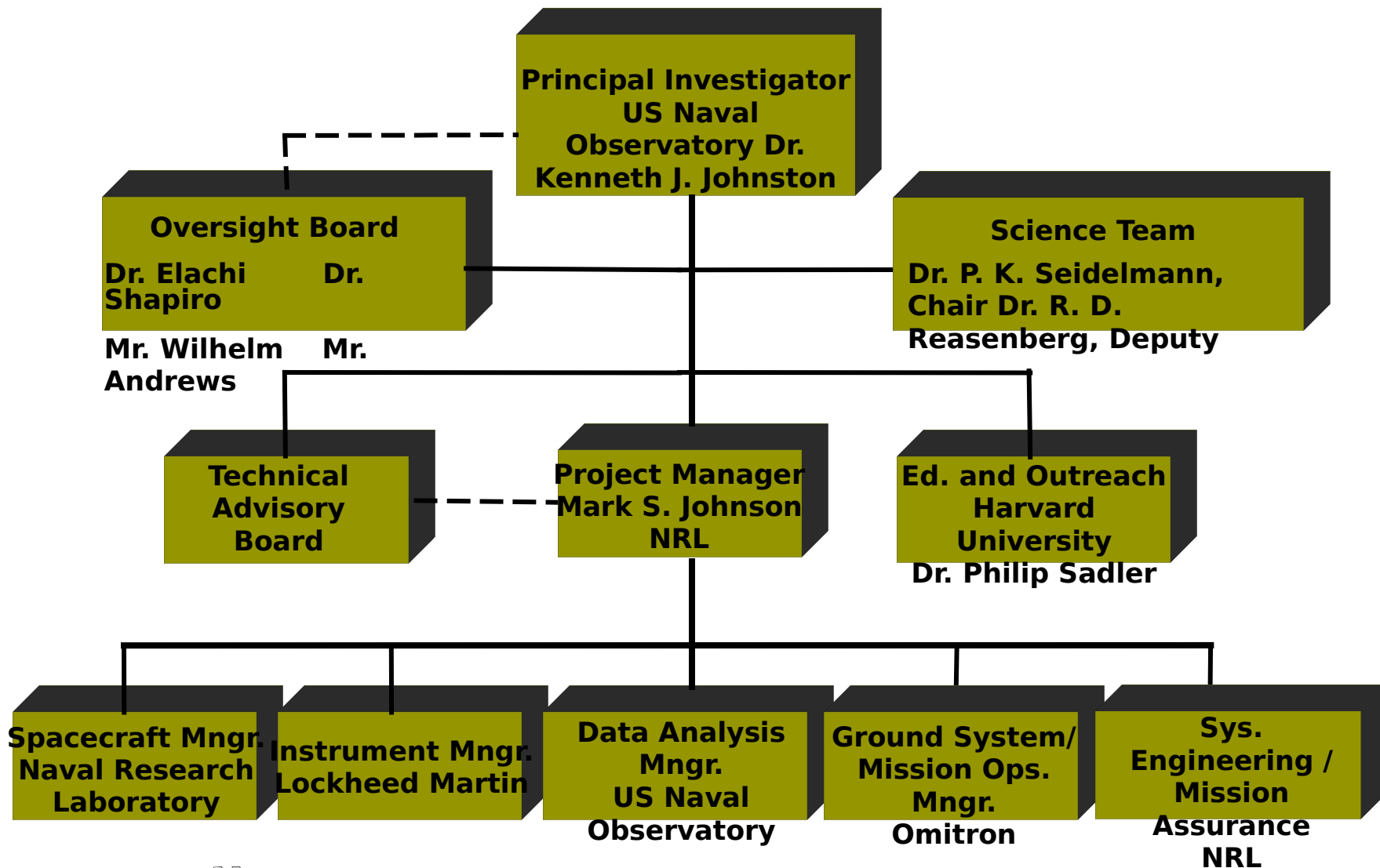


FAME Schedule

Phase A Concept Study	Feb 1999 - Jun 1999
Phase B	Oct 1999 - Jun 2000
Phase C	Jul 2000 - Mar 2001
Phase D	Apr 2001 - Jun 2003
Launch	Jul 2003
Phase E	Jul 2003 - Jan 2006
Possible DoD extended mission	Jan 2006 - Jul 2008



FAME Organization



FAME Science Team

Dr. John Bahcall, Princeton

Dr. Charles Beichman, Caltech

Dr. Alan Boss, Carnegie Inst. Wash.

Dr. Christian DeVegt, U. Hamburg

Dr. George Gatewood, U. Pittsburg

Dr. Marvin Germain, USNO

Dr. Andrew Gould, Ohio State

Dr. Thomas P. Greene, NASA Ames

Dr. Scott Horner, USNO

Dr. John Huchra, CfA

Dr. William H. Jefferys, U. Texas

Dr. Kenneth Johnston, USNO

Dr. David Latham, CfA

Dr. David Monet, USNO

Dr. Marc Murison, USNO

Dr. James Phillips, SAO

Dr. Robert Reasenberg, SAO

**Dr. Siegfried Röser,
Astronomisches Rechen-
Institut**

Dr. Allan Sandage, Carnegie Obs.

Dr. P. Kenneth Seidelmann, USNO

Dr. Mike Shao, JPL

Dr. Irwin I. Shapiro, CfA

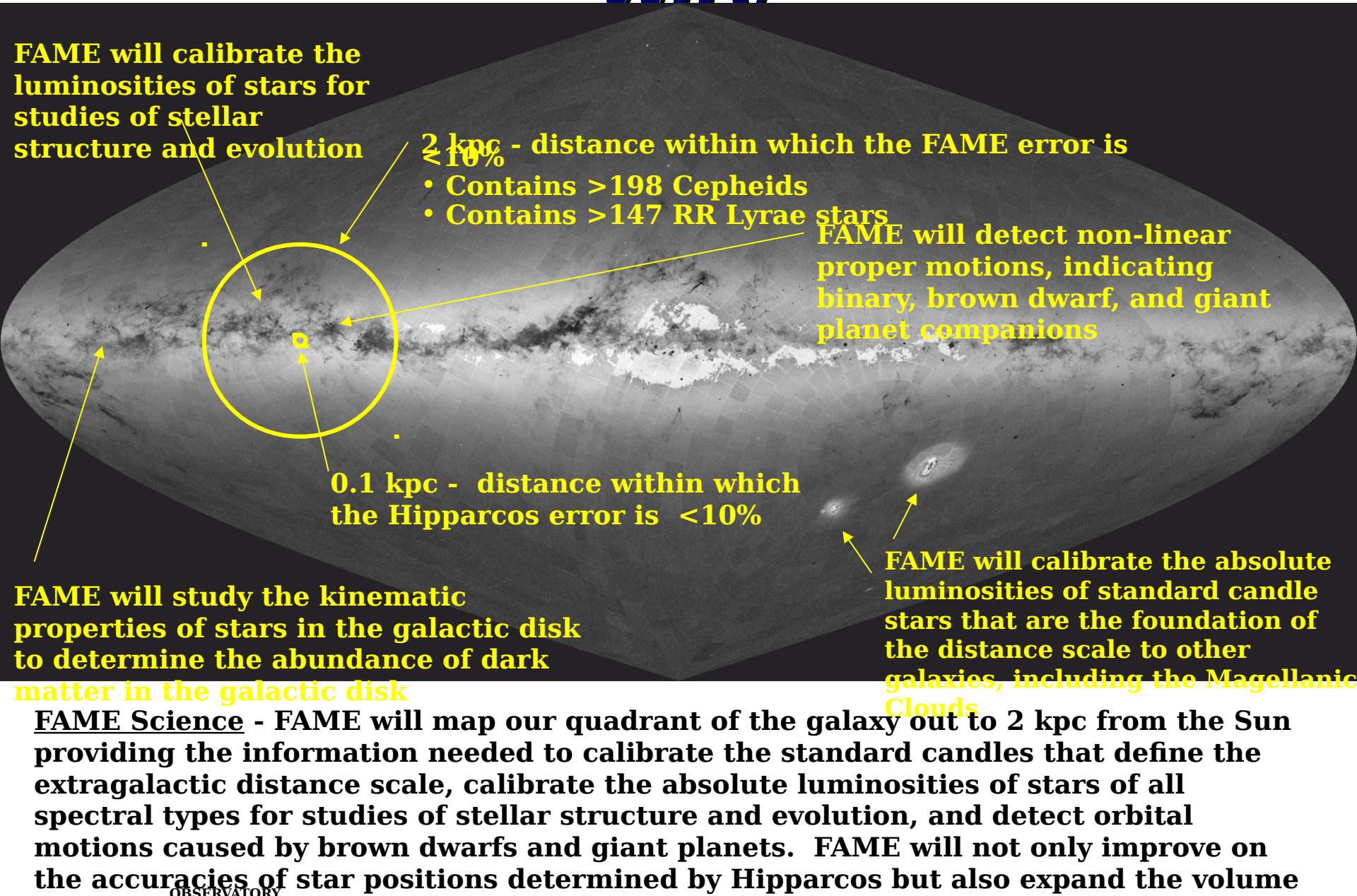
Mr. Sean Urban, USNO

Dr. William Van Altena, Yale

Dr. Donald York, U. Chicago



FAME Coverage of the Milky Way



FAME Estimated Error

Budget Totals

Visual Magnitude (m_v)	ND Filter Accuracy* (μas)	Gated Array Accuracy* (μas)
5	29	14
7	48	14
9	15	14
11	30	28
13	76	70
15	226	208

***Assumes systematic error contribution is 10 μ as**

The FAME accuracy - The predicted accuracy of FAME as a function of visual magnitude (m_v). The second column shows the accuracy if neutral density filters over 3 of the astrometric CCDs are used for astrometry of the brighter stars (baseline design). The third column shows the accuracy if the CCDs are only integrating during part of the time when a bright star is traversing the device (alternate design).



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LOCKHEED MARTIN



FAME Technology Challenges

- ✦ Centroiding accuracy of CCD in time delay integration to 1/700 pixel
- Solar radiation attitude control without thrusters
- Thermal stability of 1 mK for optical bench
- Communications link to support data downlink of 400 kbps continuous
- Microarcsecond astrometric data reduction to model all effects including aberration, relativistic effects, geodesic precession, and nutation



FAME Technology Challenges

(continued)

- ✦ **Large number of large format CCDs in the radiation environment at geosynchronous orbit**
- ▮ **Data solution for 40,000,000 stars with 4000 observations each for position, parallax, proper motion, and non-linear motions**
- ▮ **Total astrometric errors at 15 microarcseconds before photon statistics**
- ▮ **Optimum readout, on board processing, storing, tagging of data, transmission, and solutions**



USNO-901 Full-Sky Astrometric Mapping Explorer

(FAME) BUDGET TOTALS (\$K)

1. SCIENCE	1903
2. INSTRUMENT PAYLOAD	23973
3. SPACECRAFT	33040
4. GROUND SYSTEM	4353
5. INTEGRATION (MSI&T)	1206
6. LAUNCH	43119
7. OPERATIONS	5630
8. MO & DA	14476
9. EDUCATION/OUTREACH	982
10. RESERVE	8675
<hr/>	
TOTAL	137357



USNO-901 Full-Sky Astrometric Mapping Explorer (FAME)

LAUNCH BUDGET

Boeing Delta II 7425 or 7426 launch service procured under the NASA Med-Lite Contract (in \$K)

FY 01	FY 02	FY 03	FY 04	TOTAL
9400	18500	17500	5600	51000

LAUNCH COSTS IN REAL YEAR DOLLARS



USNO-901 Full-Sky Astrometric Mapping Explorer (FAME)

STATUS

- **Selected for Concept Study in NASA MIDEX in FY 99**
 - **Five selected for Concept Study, 2 to be selected to go ahead**
 - **Current cost estimate of \$140M**
- **Seeking funding from:**
 - **International collaboration**
 - **Navy**
 - **Air Force**
 - **To reduce NASA cost & improve competitive position**



USNO-901 Full-Sky Astrometric Mapping Explorer (FAME)

POSSIBLE SUPPORT

♦ **Integration Costs:** **FY01 \$432K**

FY02 \$718K

▢ **Partial cost of Launch:** **FY04 \$5.6M**

▢ **Cost of Extended Mission:** **FY05 \$2.9M**

FY06 \$3.0M

FY07 \$3.1M

Prefer Support for Launch or Extended Miss



Summary

- **Meet the requirements for star positions in 2010 and beyond**
- **Redefines reference frame**
- **Technology leading to space navigation at meter accuracies**
- **FAME will determine accurate positions, parallaxes, and proper motions for 40 million stars**
- **FAME has been selected by NASA for a Phase A Concept Study**

